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Toxic and Hazardous Materials Agency

TECHNICAL AND ECONOMIC EVALUATION OF AIR STRIPPING FOR VOLATILE ORGANIC COMPOUND (VOC) REMOVAL FROM CONTAMINATED GROUNDWATER AT SELECTED ARMY SITES

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PREPARED BY:

TENNESSEE VALLEY AUTHORITY
National Fertilizer and Environmental Research Center
Muscle Shoals, Alabama 35660-1010

JULY 1991

TECHNICAL AND ECONOMIC EVALUATION OF

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FOR

USATHAMA

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Tennessee Valley Authority

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Technical and Economic Evaluation of Air Stripping for Volatile Organic Compounds (VOC) Removal from Contaminated Groundwater at Selected Army Sites

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This report provides a process and economic evaluation of the use of air stripping to remove VOC's from contaminated groundwater on or near three existing U.S. Army facilities. The three sites visited were: (1) Twin Cities Army Ammunition Plant (TCAAP), Minneapolis, Minnesota; (2) Letterkenny Army Depot (LEAD), Chambersburg, Pennsylvania, and (3) Sharpe Army Depot (SHAD), Lathrop, California. The evaluation focused on the economics of each site to determine (1) the total capital cost for the existing treatment facilities, (2) the operating costs for each existing facility, and (3) to identify the significant cost drives for each facility.

The three sites varied in design and operating philosophy due to the geographical locations and the demands placed on the systems. TCAAP and LEAD required heavy freeze protection while SHAD required none. LEAD included carbon absorbers while TCAAP and SHAD had none. Materials of construction varied from steel to fiberglass-reinforced plastic (FRP) to

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19. plastics (PVC).

The installed costs of each facility were determined and compared using total life cycle costing (TLCC) analysis based on 1,000 gallons of water treated over the life of each plant. The operating costs were also determined and compared based on 1,000 gallons of water treated.

The work was conducted by a project team from the Development Division of the Tennessee Valley Authority's Fertilizer and Environmental Research Center (NFERC) under Army Contract No. TV-79415T. The study was conducted for the United States Army Toxic and Hazardous Materials Agency (USATHAMA) under a scope of work originally proposed in July 1989.

TABLE OF CONTENTS

I. SUMMARY

This study provides a process and economic evaluation of the use of air stripping to remove VOCs from contaminated groundwater on or near Army facilities. The main objective of the study was to determine the capital and operating costs for existing Army facilities. Additionally, the practices of VOC stripping are described in detail.

Data for the study were obtained from three existing air-stripping facilities at (1) Twin Cities Army Ammunition Plant (TCAAP) near Minneapolis, Minnesota; (2) Letterkenny Army Depot (LEAD) in Chambersburg, Pennsylvania; and (3) Sharpe Army Depot (SHAD) in Lathrop, California. An investigation was performed at each site to (1) determine the capital costs for the existing treatment facilities, (2) determine the operating costs for the existing facilities, and (3) identify significant cost factors for each of the facilities.

Because of the different locations and demands placed on the stripper units, the three facilities vary in design and operating philosophy. The size of the units range from 200 gallons/minute at LEAD to 2,900 gallons/minute at TCAAP. The TCAAP and LEAD units are located in cold climates and require extra freeze protection, while the unit at SHAD is essentially in the open. The unit at LEAD also contains liquid- and vapor-phase carbon absorbers to further reduce the VOC emissions; this was found to be a major cost item from both a capital and an operating standpoint.

The operating personnel requirements vary according to the level of sophistication of the control and data-gathering equipment installed at each unit.

The materials of construction of the strippers vary and include steel, fiberglass-reinforced material, and plastics being used in all three facilities.

The existing units were found to be operating within the required environmental discharge limits.

The total capital investment and operating costs (excluding capital charges) for the three existing air stripping plants were found to be:

Plant	Flow, GPM	Capital, $	Operating $/1,000 gal	TLCC $1,000 gal
TCAAP	2,900	8,034,454	.1214	.2971
LEAD	200	2,054,145	.6671	1.3185
SHAD	300	1,383,163	.1518	.4442

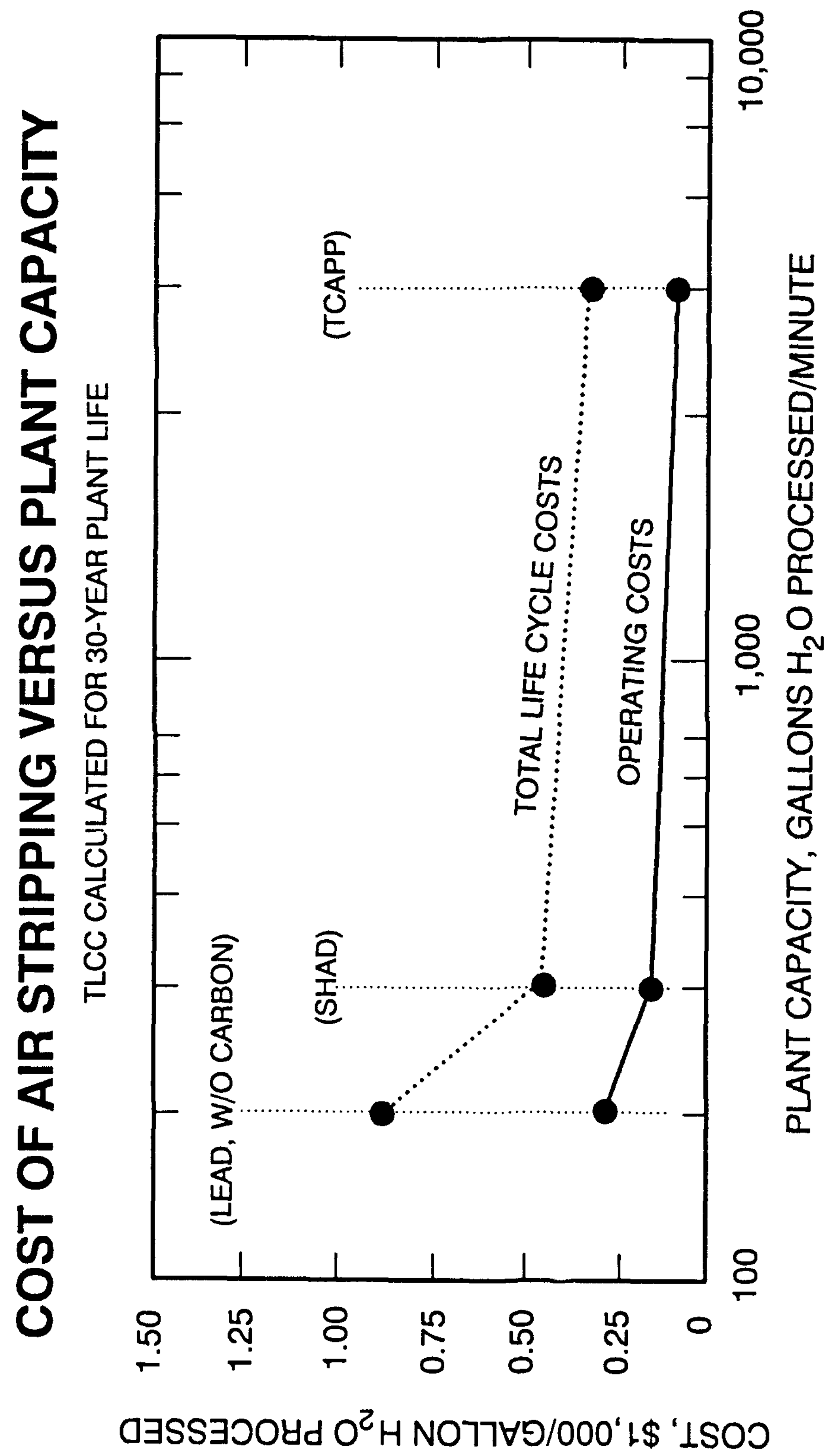
The operating costs per 1,000 gallons shown above was calculated using the annual operating cost discounted over the 30 year life of the plant. See Section V for details.

For the LEAD facility the use of carbon absorption completely overshadowed any cost associated with the basic air-stripping process. If the carbon absorbers were not required, the operating costs would be approximately $.27 per 1,000 gallons.

The most significant cost drivers, as defined in paragraphs 5.1.4, for the basic air-stripping operation were found to be:

- Air Stripping Tower Capital Cost
- Utilities
- Maintenance Contracts
- Carbon Absorbers (LEAD)

Shown in Figure 1 is the total life-cycle cost (TLCC) (including capital costs) and the operating costs (excluding capital charges) per 1000 gallons of water treated for the three sites. With each site having varying capacity, the potential for economy of scale can be seen. Although the designs for each plant are not identical, there is a reasonable correlation that can be used for projecting approximate future costs.


COST OF AIR STRIPPING VERSUS PLANT CAPACITY
TLCC CALCULATED FOR 30-YEAR PLANT LIFE
(LEAD, W/O CARBON)
(SHAD)
(TCAPP)
TOTAL LIFE CYCLE COSTS
OPERATING COSTS
1.50
1.25
1.00
0.75
0.50
0.25
0
100
1,000
10,000
PLANT CAPACITY, GALLONS H2O PROCESSED/MINUTE
COST, $1,000/GALLON H2O PROCESSED

II. INTRODUCTION

This report presents a technical and economic evaluation of the use of air stripping to remove volatile organic compounds (VOCs) from contaminated groundwater at three selected Army sites. The economic evaluation was performed to determine the capital and operating costs for the plants as they exist. General guidelines for designing and evaluating new air-stripping facilities are also included.

The work was conducted by a project team from the Development Division of the Tennessee Valley Authority's National Fertilizer & Environmental Research Center (NFERC) under Army Contract No. TV-79415T. The study was conducted for the United States Army Toxic and Hazardous Materials Agency (USATHAMA) under a scope of work originally proposed in July 1989.

III. PROCESS DESIGN

3.0 Process Design

This section provides information concerning the principles of air stripping for removing VOCs from contaminated groundwater, physical description of towers, applicability of air strippers for VOC removal from groundwater, and factors to consider when designing air strippers.

3.1 Principles of Air Stripping

Air stripping represents controlled contact of a liquid containing volatile contaminants with a clean stream of air. Ideally, the entire volatile component is transferred from the liquid to the air/vapor phase. In a liquid-vapor contactor, such as a packed-column air stripper, the mass transfer rate from liquid to vapor is controlled by approaches to the equilibrium concentration of the compounds in the water and the air at the specified conditions. This mass transfer capability is represented by Henry's Law constant of each compound in the liquid and gaseous phases.

Henry's Law constant reflects the relative volatility of each compound; that is, how easily the compound can be transferred from the liquid to the vapor. According to Henry's Law, the concentration of VOC in the water and the air will be a function of the total VOC vapor pressure. Values for Henry's Law constants for various compounds can be either calculated or obtained from the literature. Compounds with large Henry's Law constants are more easily removed from the water stream than compounds with lower values. Henry's Law constants are very temperature dependent. Many VOCs can be air stripped at ambient temperature; however, those compounds with low volatilities at ambient temperature may require preheating of the groundwater before it enters the stripper.

Economic studies have shown that air stripping is recommended as the most cost-effective method for treating groundwater contaminated with VOCs. Air stripping offers effective VOC removal at reasonable capital and operating costs. Air stripping is probably the most common method used in removing VOCs from groundwater, especially where the groundwater contamination involves low solvent concentrations (in the µg/L range) and in areas of the country where the treatment facility is located in remote locations. Under these conditions, air stripping is favored since VOC-laden exhaust air can often be released uncontrolled to the atmosphere without significant impact on ambient air quality. When effluent water quality is critical, multiple air strippers (in series) can often be used to remove VOCs below detectable limits.

Carbon absorption can also be used in conjunction with air stripping to remove VOCs from the groundwater; however, this method is much more expensive than air stripping alone. Carbon absorption, although highly effective, is not normally used unless the influent water quality is such that air stripping by itself will not purify the water.

The efficiency of air strippers is dependent not only upon the Henry's Law constant of the VOCs in the water stream, but also on the packing in the tower, the air flow rate and temperature, and the liquid flow rate and temperature. The amount of packing used in the tower will be determined based on the diameter and height of the tower. The type of packing is also of importance.

For most air strippers, the diameter of the tower will depend upon the quantity of air and water being handled, physical and chemical properties of the water, and the ratio of air to water. The height of the tower, as well as the total packing volume, depends on the influent concentration of the groundwater and the desired effluent concentration of the water, as well as the mass transfer/unit of the packing.

Most tower shells are constructed of the least expensive and the most durable material available. Fiberglass-reinforced plastic is most common, although carbon steel or other alloys may be used.

3.2 Internals of Air Strippers

The internals of air strippers consist of a main body of packing, support plates, and a liquid distributor to spray liquid over the bed of packing. The tower internals will be discussed in more detail in the following sections.

3.2.1 Column Packing

Packing in an air stripper is designed to increase the liquid surface area exposed and to allow even distribution of liquid and vapor over the cross section of the tower. Characteristics of packing are an important consideration in column design; the packing will contribute greatly to the overall performance of the stripper.

The packing should be able to operate over a wide range of gas-to-liquid (G/L) ratios and be resistant to entrainment, corrosion, fouling, and fracturing.

Column packing comes in a myriad of materials, forms, and sizes; and is of three basic types: (1) random dump, (2) structured grid, and (3) high-efficiency mesh. Random-dump packing normally ranges from 0.5 to 3.5 inches in diameter. It may be of various configurations, for example, ring-shaped or saddle.

3.2.2 Liquid Distributors

In order for packing to perform properly, the liquid must be distributed evenly over the packing surface area. Often, poor column performance is a result of improper or inadequate liquid distributors. A wide variety of distributors are available, each having advantages and disadvantages. A V-notched distributor has a high potential turndown, low fouling potential, and high maximum flow rate. The water is distributed by troughs with V-shaped notches along the sides. V-notched distributors are suitable for columns that are greater than or equal to three feet in diameter. These distributors operate by gravity flow and are level sensitive. Columns containing V-notched distributors must be perfectly level for optimum operation performance. To avoid leveling problems from fixed distributors, liquid distribution can be accomplished using spray nozzles. However, spray nozzles are subject to fouling, have low turndown ratios, limited maximum flow rates, and high pressure drop in the nozzles.

3.3 Applicability of Packed Air-Stripping Columns

The packed air-stripping column is useful for difficult separations requiring a high degree of removal. Advantages of an air stripper include excellent removal efficiency, high mass flow, large range of G/L ratios, and low pressure drop. Disadvantages include potential fouling which causes significant gas pressure drop.

Selection of the proper packing can often reduce or eliminate potential fouling. Fouling problems may also be eliminated by pretreating washwater using a sand filter.

3.4 Design Criteria for Air Strippers

This section discusses several practical guidelines for designing an air-stripper column. Key factors affecting design of air strippers are the water flow rate, water temperature, contaminant concentration, and allowable effluent limits. Other factors which will play a role in the design and operation of the air stripper include being able to ensure proper cleanliness of the tower, the structural integrity of the tower, the tower packing, and the internals as well as distributors and support plates.

3.4.1 Water Flow Rates

The diameter of the tower is directly related to the water flow rate through the tower; the liquid loading rate is usually expressed in gallons/minute (gal/min) and/or gallons/minute/square foot (gal/min/ft^2). Over-estimating the flow rate of water to the tower will result in higher capital and operating costs. If the flow rate of water to the tower is under-estimated, it could result in a tower incapable of handling the required flow or flooding.

3.4.2 Water Temperature

In addition to the flow rate, the temperature of the groundwater is an important factor in designing the tower. The tower should be designed based on the water at the lowest expected temperature. At colder water temperatures, the VOCs are more difficult to remove; as the water temperature increases, the VOCs are more easily transferred to the air. If the designed water temperature is estimated too high, it is possible to under design the tower and risk not being able to meet required effluent levels of the contaminants involved.

For cold-weather climates, provisions must be made for insulation and heat tracing of the tower sump and piping to prevent freezing. It may also be necessary to partially or completely enclose the air-stripping facility in certain geographical locations due to the extreme cold.

3.4.3 Contaminant Concentration

An accurate analysis of the contaminant is an important criteria in the design. As mentioned earlier, the effectiveness of removing VOCs from contaminated groundwater is determined by Henry's Law constant. It is therefore important to know the type of contaminant as well as the concentration of the contaminant. The tower design is usually sized based on the compound with the highest concentration, but the relative ease with which the compounds can be removed from the groundwater also factors into the configuration of the tower.

Therefore, if a tower is designed to remove those compounds with low Henry's Law constants, the same tower should also be able to remove those with high Henry's Law constants.

3.4.4 Air:Water Ratio

Higher air:water mass ratios give much higher VOC removal rates, but also result in higher operating costs. In general, the higher the air:water ratio, the more contaminant is removed. However, if the air:water ratio is too high, it can cause problems with excessive pressure drop through the tower. This can also lead to flooding in the tower. In a packed tower with a definite flow of liquid, there is an upper limit to the rate of air flow. The air velocity corresponding to this limit is called the flooding velocity. Flooding can be observed in a tower when there is a holdup of liquid in the tower due to high gas velocity or it can also occur with an excess of liquid flow through the tower. Other problems observed with a high air:water ratio is a mist of liquid carryover out of the packed tower with the exit gas. Practical design has shown air:water ratios in the range of 30:1 to 40:1 were sufficient for a packed tower to achieve removal of at least 95 percent or greater for trichloroethylene.

Air supplied to the tower should be passed through impingement-type filters to remove dust, insects, and any other unwanted materials. Dust and other debris could contribute to tower fouling or biological growth.

3.4.5 Sump Cleanup

The air-stripping process creates an oxidizing environment in the water due to high aeration rates. Minerals in the water such as iron or manganese tend to oxidize in the air stripper and precipitate in the sump. High iron values may also promote the growth of iron bacteria on the tower packing which can create additional fouling problems. Access to the sump for cleaning is recommended when designing a system. Provision should be made for periodic acid washing or hydrogen peroxide cleaning of the packing. In some areas of the county where the water has a high iron content, the water may already have a high pH level. The air stripping process may raise the water pH higher due to the stripping of carbon dioxide gas from the water. A laboratory analysis of the liquid feed will give insight into packing fouling or plugging tendencies.

3.4.6 Structural Integrity of the Tower

The structural integrity of the tower also needs to be assured. Once the location of the tower is known, determinations need to be made relative to the seismic zone and wind speed, as well as the hydraulic load on the tower. The seismic zone takes into account placement of a tower in areas of the United States where damage from an earthquake presents risk. The same is true for wind loading. Some areas of the country can experience winds in excess of 110 miles/hour, while other experience a maximum of 70 miles/hour. The tower should be constructed in accordance with the geographic site location. Hydraulic loading is the calculated weight of the tower during operating conditions. These conditions include the weight of the tower shell and internals, packing, and water in the tower. The shell of the tower must be able to withstand all of the above loads without sustaining any structural damage such as cracks or buckling.

3.4.7 Tower Packing

Wall effect is greater with small-diameter towers. Tower columns should have internal features to redistribute drippage and support packing. A good rule of thumb is to use packing material in size which is 1/10 the diameter of the column itself. If the ratio of tower diameter to packing diameter is less than 8:1, the liquid tends to flow out of the packing and down the walls of the column. This is known as channeling.

Uniform distribution of the liquid throughout the column is the single most important safeguard against channeling in packed columns. Channeling is usually more evident in small-diameter towers. Channeling will result in reducing the liquid residence time in the tower. If channeling occurs, it will cause a partial or total bypass of the packing for that fraction of the liquid flow. The migration of liquid toward the tower walls is usually not a problem with large-diameter columns because the initial uniform liquid distribution is usually sufficient to ensure good column packing performance.

The type of packing used in the air stripper is important in the performance and operation of the tower. Packing should provide surface area to spread water as thin as possible. The characteristics of the packing have significant impact on the tower's mass transfer coefficient. Packing variables which affect mass transfer coefficient of the tower include the surface area, the number of drip points in each piece of pack, the pressure-drop characteristics, as well as the ability of the pack to become uniformly wet. The better the mass transfer characteristics of the pack, the more efficient it is. Increased packing efficiency results in a lower packing height, as well as overall height of the tower. An increase in packing depth usually increases the percent removal, although there is a structural as well as theoretical limit as to how much packing can be used in a tower. The amount of packing in a tower also affects the total pressure drop through the tower. Therefore, packed towers are commonly designed on the basis of a definite pressure drop/unit height of packing.

Even with rigorous cleaning, the packing used in the tower will eventually need to be replaced. A well-engineered tower design will help to facilitate the replacement process. Especially helpful in this respect are manways which are located at strategic points on the tower shell so that packing and other internals can be removed.

3.5 Future Design Considerations

To aid in the future design of additional air strippers for other Army installations, we have included a software program package with this report. The title of the program is "Theory and Design of Countercurrent Packed Aeration Towers." The program will allow the user to input process variables to allow quick and easy design to an air-stripper system. Among the variables which are input for the system design are the type of contaminant and its concentration, the type of packing to be used, the temperature of the water, the minimum packing depth required and the maximum packing depth allowed, the liquid loading rate and a minimum/maximum air-to-water ratio. Based on these variables, the program will determine the effluent concentration of the groundwater after it exits from the tower and the percentage of contaminant which was removed. The program will give a range of concentration levels remaining in the exit water from the tower at various air-to-water ratios and packing depths in the tower. The user can then select the air-to-water ratio and packing depth that best meets their needs.

IV. SITE DESCRIPTIONS

4.0 Site Descriptions

The three facilities were visited to obtain design, operating and maintenance information required to perform the process and cost analysis for each site.

4.1 TCAAP

TCAAP is located in New Brighton, Minnesota, about 13 miles north of Minneapolis/St. Paul in northwestern Ramsey County. It covers approximately four square miles. The installation was constructed in 1941 and 1942, and was used for the production, inspection, and storage of ammunition until approximately 1957. After a period of standby the site was used again from 1966 through 1974.

Previous studies have shown that underground water aquifers at TCAAP are contaminated with a variety of VOCs. These contaminants and concentrations are:

Influent	Concentration, μg/L
1,1-dichloroethylene	160
1,1-dichloroethane	47
cis-1,2-dichloroethylene	56
Chloroform	3
1,1,1-trichloroethane	950
Trichloroethylene	3,400
Tetrachloroethylene	3

It has also been determined that most of these VOCs in the groundwater can be traced to the methods of disposal of explosives, solvents, oil, and other organic materials at TCAAP. In an attempt to properly remediate the underground aquifer at TCAAP, it was decided that the most cost-effective method would be to build a water treatment site which employed the use of VOC packed-tower strippers using ambient air as the cleaning medium. Figure 4.1-1 is a photograph of the water treatment site at TCAAP. Figure 4.1-2 is a flowsheet of the process as it is currently being operated. The water treatment site at TCAAP consists of four air strippers which are operated on a continuous basis to process approximately 2,900 gallons/minute (gal/min) of water. The treatment unit originally consisted of three towers, but the fourth tower was added in 1988 when pumping capacity to the plant was increased to 2,900 gal/min. The towers (numbered 1 to 4) are enclosed in a heated metal building to a height of 8 feet; the remaining portion of the towers extend through the roof of the enclosure. Each tower has a total height of 34 feet. The effective packing height of each tower is 24.5 feet. The towers are constructed of carbon steel. The piping associated with the towers is ductile iron. Towers 1 and 2 are both 7 feet in diameter, while towers 3 and 4 are 8 feet in diameter. The four towers serve to make up two trains which operate in parallel. Tower 1 and 4 operate in series to form train 1, while tower 2 and 3 are operated in series to form the second train. A 16-inch-diameter inlet water line to the treatment plant carries about 2,900 gal/min to the plant. Once the water supply enters the enclosure, it splits and the lines reduce to 8 inches in diameter and carry 1,450 gal/min of water each to towers 1 and 2. After the water exits the outlet of tower 1, it enters a wet well. From this wet well, the water is pumped up to the top of tower 4 for its final scrubbing.

The water pumped into the top of tower 2 exits into a second wet well. From here, the water is pumped to the top of tower 3 for final scrubbing of VOCs. The clean water from towers 3 and 4 is mixed as it exits each tower and enters a third wet well. All three wet wells are 20 feet by 20 feet by 8 feet in size. The water from the third wet well is pumped through a 16-inch-diameter line to a gravel and sand pit where the water is allowed to reenter the underground water table. The gravel and sand pit is located onsite, about 5,300 feet

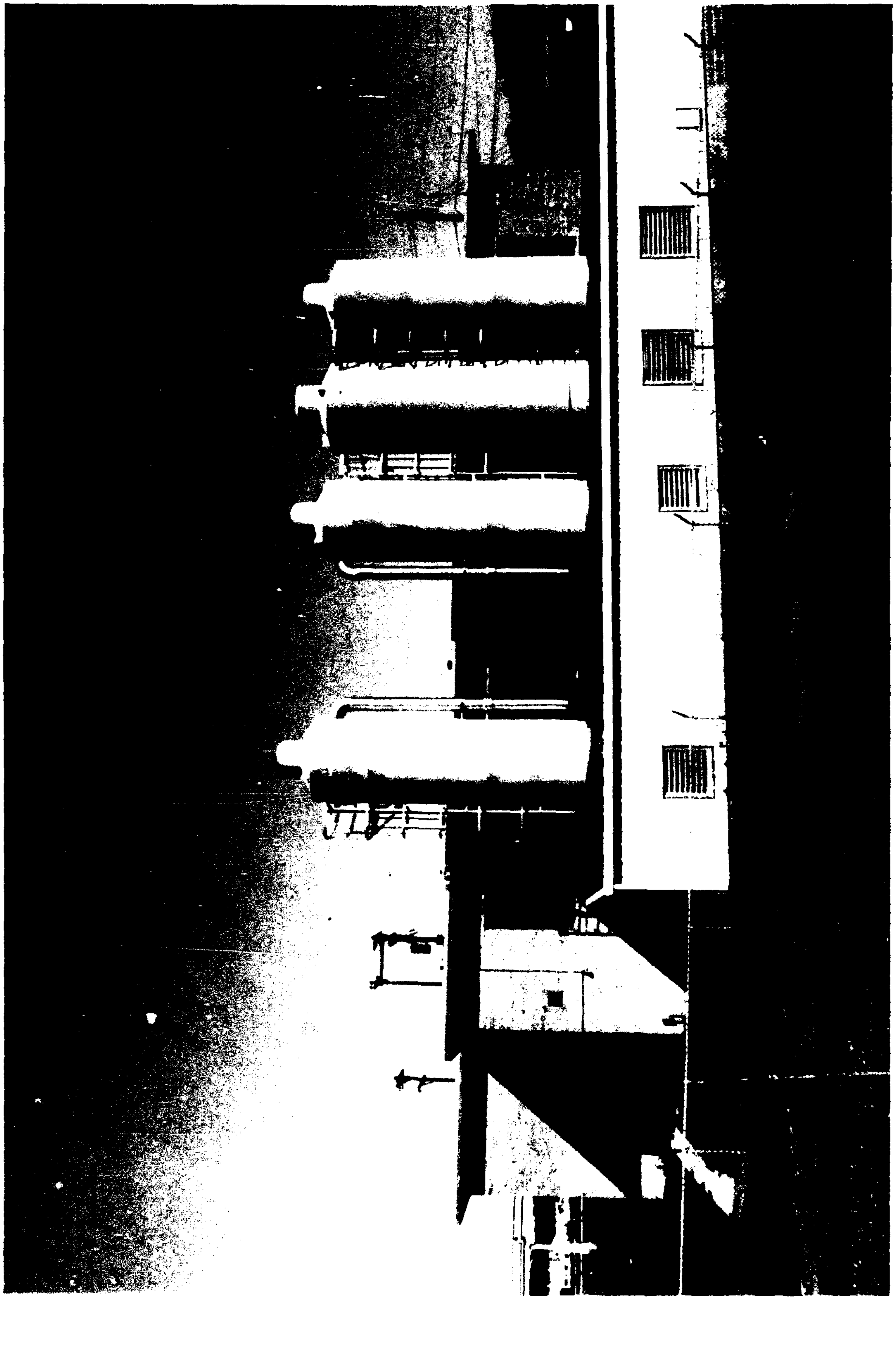


Figure 4.1-1
VOC Water Treatment Plant at Twin Cities Army Ammunition Plant

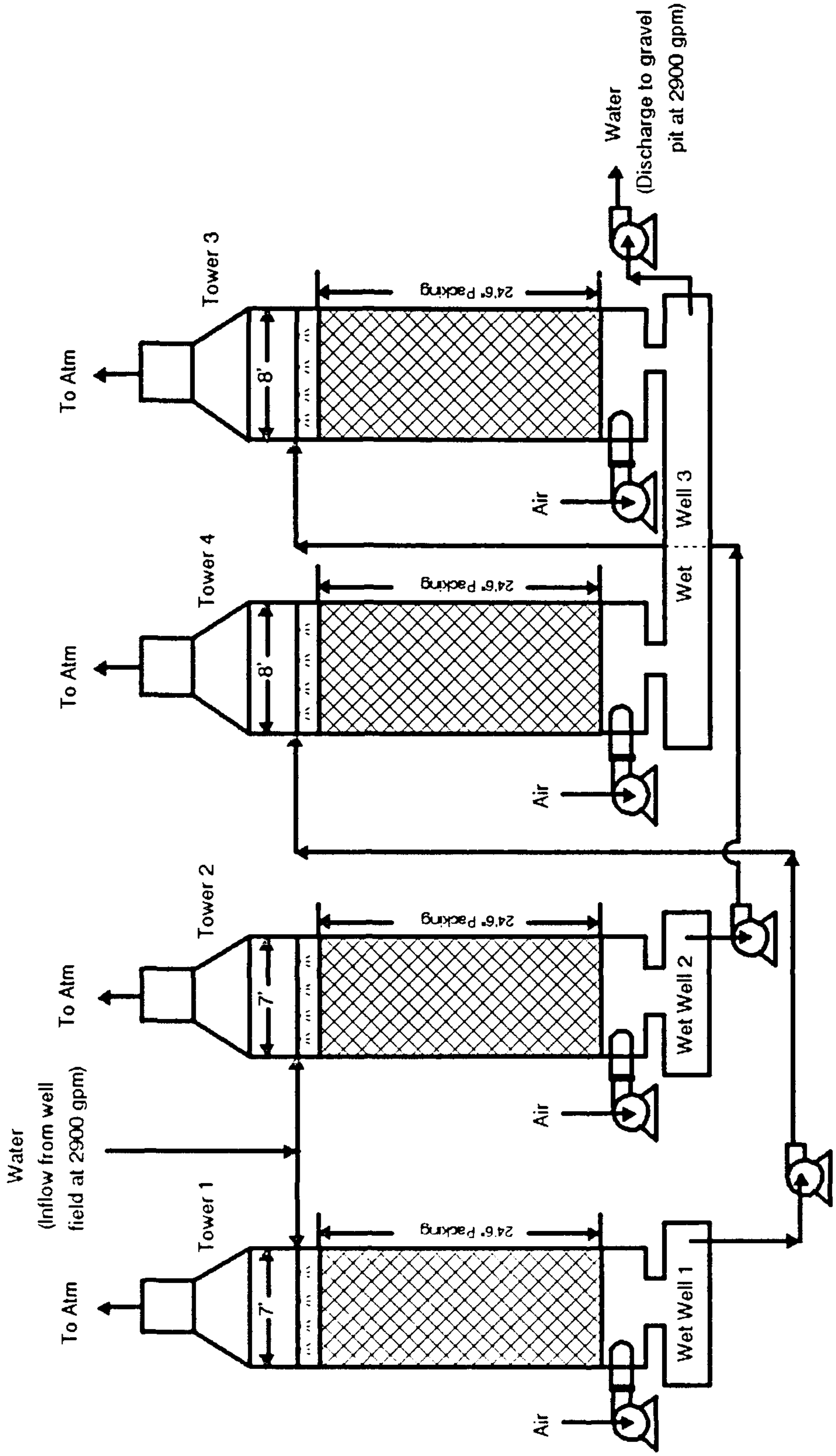


Figure 4.1-2

Flowsheet of Water Treatment Plant at Twin Cities Army Ammunition Plant from the water treatment facility. The kame deposit at the gravel pit represents an ideal discharge point for allowing the water to filter back into the underground aquifer.

Towers 1, 2, and 3 all use three-inch Intalox saddles for packing, while tower 4 uses three-inch Lanpac. Each tower has its own separate blower. Air is blown countercurrent to the flow of water in each tower. The blower capacity for towers 1 and 2 is 5,100 cubic feet/minute (ft^3/min) of air. The blower capacity for towers 3 and 4 is 9,850 ft^3/min. For towers 1 and 2, the air:H_2O mass ratio is 25:1; while for towers 3 and 4, the air:H_2O ratio is 50:1.

The contaminated water is pumped to the treatment site from 12 boundary wells and 4 source control wells which are located in areas identified as having underground contaminated water. Each well has its own separate pump which is totally enclosed for cold weather protection. The typical pumphouse is constructed of 8-inch concrete blocks and is about 8 feet by 13 feet in size. The four source control wells pump either 45 or 60 gal/min of water. All of the well pumps have a 6-inch impeller except for one boundary well pump which has a 4-inch impeller. The discharge on each pump is constructed of schedule 40 galvanized steel with a recovery well steel casing enclosing each pump. Each pump has a turbo flow meter located inline to monitor the water rate. There is also a motorized check valve and gate valve located at each pump.

The forcemain collection system includes a pumphouse for each of the 16 pumps along with 16 return well structures and associated valves and controls. The return pipe is installed in a trench 7 feet underground and ranges in size from 6 to 16 inches in diameter. The piping in the forcemain is constructed of ductile iron.

The plant is equipped to operate automatically with little need for constant staffing of personnel. An operator normally makes routine visits to the plant once each day. The operator will spend approximately one hour at the site checking the system, recording meter readings, and making minor repairs.

4.2 LEAD

LEAD is located in Franklin County, Pennsylvania, about 5 miles north of the city of Chambersburg, Pennsylvania. The depot was established in 1942 with the primary mission of ammunition storage and shipping. Since 1942, the depot's mission increased to include (1) overhauling, rebuilding, and testing of wheeled and tracked vehicles; (2) issue and shipment of chemicals and petroleum products; and (3) maintenance, demilitarization, and modification of ammunition. Operations currently conducted at the depot include cleaning and stripping, plating, lubrication, demolition, chemical and fuel oil transfer, and storage and washout/deactivation of ammunition. Several of these activities involve the use of trichloroethylene, other solvents, lubricants, corrosives, and various metals. LEAD is the owner/operator of two industrial wastewater treatment plant (IWTP) lagoons. Initially, there was only one lagoon which was built between 1954 and 1957. It was unlined and had an operating capacity of one million gallons. This unlined lagoon reportedly contained sludges, oils, and industrial wastes. The sludge and waste material leaked from the bottom of the lagoon into the underground water aquifer resulting in contamination of the groundwater.

In 1967, the lagoon was rebuilt to prevent further leakage. There are now two concrete-reinforced lagoons constructed within the original lagoon perimeter. The current concrete-lined lagoons remain potential contaminant sources due to cracks discovered in the bottom of the southern lagoon. The active use of these lagoons has been totally discontinued since December 1987 in preparation for their closing.

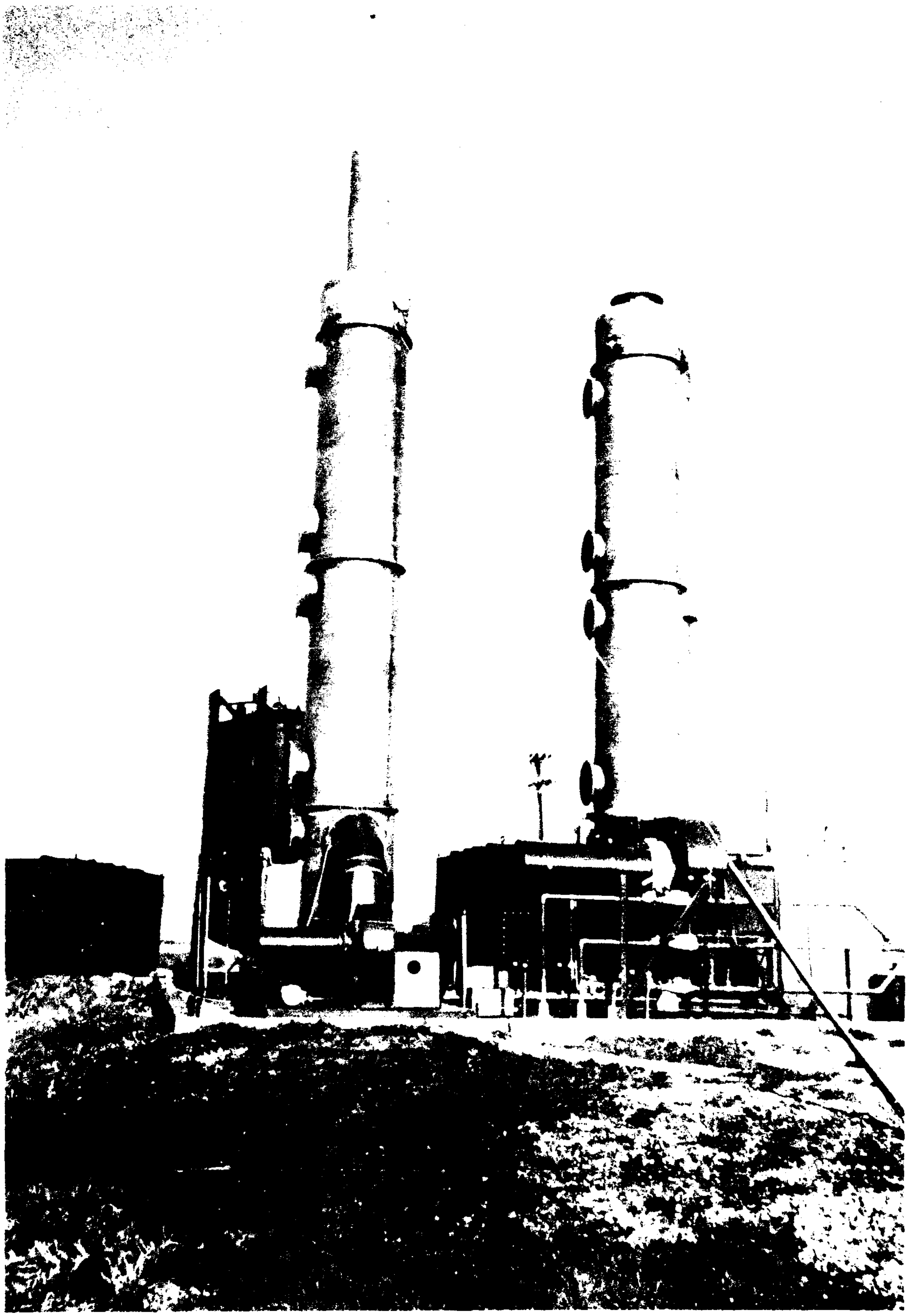
Two significant volatile compounds historically identified in groundwater near the IWTP lagoons are trichloroethylene and trans-1,2-dichloroethylene. The listing of VOCs found in the groundwater along with the concentration of each contaminant is given as the following:

Influent	Concentration, µg/L
1,1,1-trichloroethane	666
1,1-dichloroethylene	810
trans-1,2-dichloroethylene	700,000
Trichloroethylene	370,000
Tetrachloroethylene	34

In order to remediate the groundwater at the IWTP lagoons, a water treatment plant was built which utilized air stripping followed by carbon adsorption. Filtration pretreatment was added to the facility based on reports of water quality, which were received from the initial well drilling and testing of the groundwater. These tests indicated the presence of 80 to 160 micrograms/liter (µg/L) of suspended solids in the samples. Initial treatment provided a system of wells capable of continuously pumping 80 gal/min of contaminated groundwater from near the IWTP lagoons to remove the VOCs. Air stripping was selected as the primary treatment technology. However, because of concerns from the Pennsylvania Department of Environmental Resources (PADER), a carbon absorption system was also incorporated into the air-stripping facility so that the exit air and exit water would be treated with carbon before being discharged from the plant.

Figure 4.2-1 is a photograph of the treatment site at LEAD before it was enclosed in a weatherized building. Figure 4.2-2 is a process flowsheet of the site. Two 4-foot diameter towers made of fiberglass-reinforced plastic were constructed with each tower containing 20 feet of 3.5-inch Jaeger tri-pack poly packing. Initially, three 200-feet deep recovery wells (R1, R2, and R3) were used as groundwater monitoring points. Each extraction well recovery system was installed using schedule 80 PVC piping which was laid in a 48-inch-deep trench. Direct routing of the three separate lines was

Figure 4.2-1
VOC Water Treatment Plant at Letterkenny Army Depot



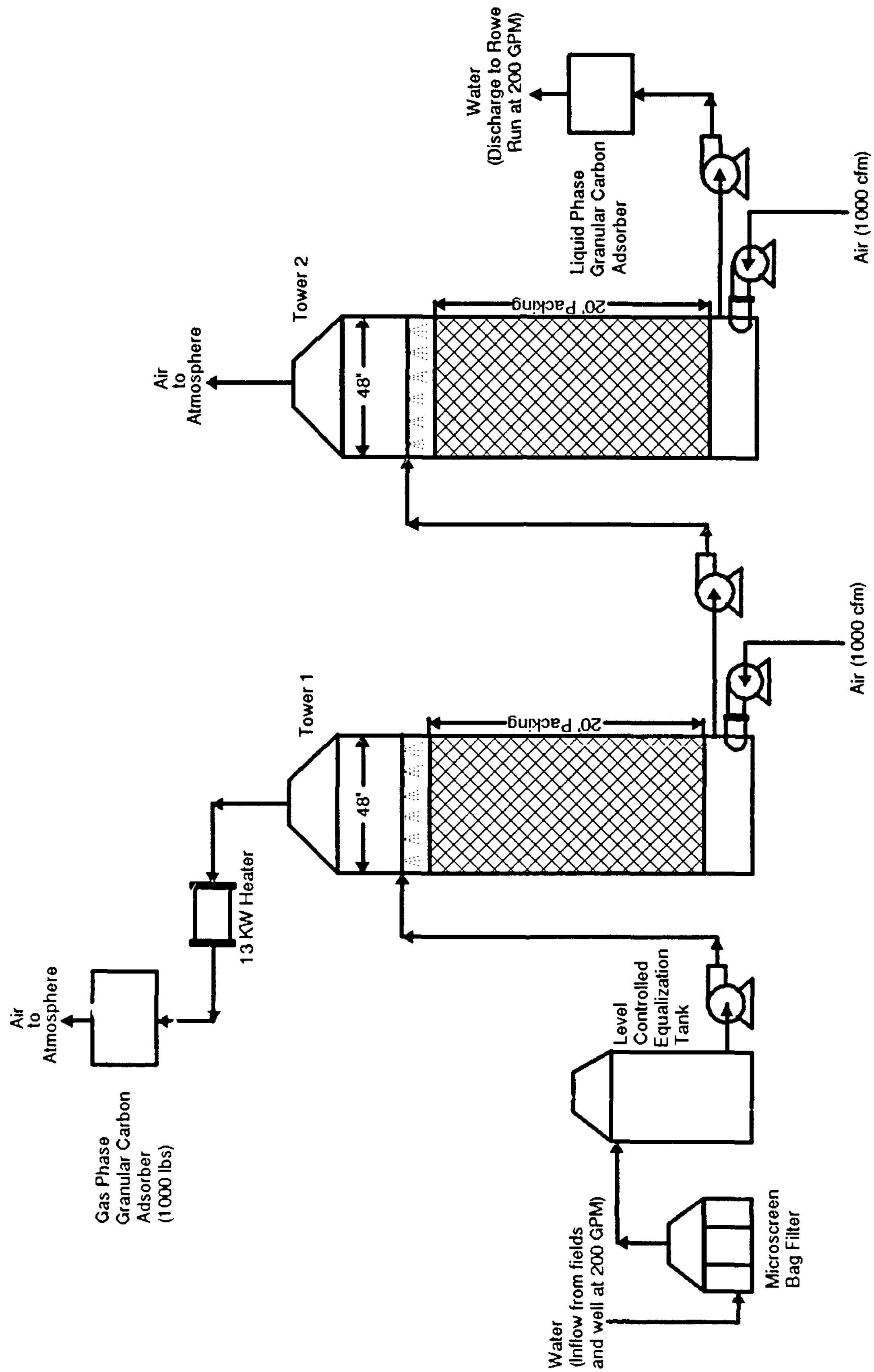


Figure 4.2-2

Flowsheet of Water Treatment Plant at Letterkenny Army Depot selected to pump and control each well independently. Each well was equipped with flow totalizers and valves for flow adjustments. The well connections were 2 inches in diameter with the line sizes increasing to 3 inches in diameter approaching the treatment site.

About one year after the treatment site began operations, seven additional wells were installed at the facility. These additional wells increased the pumping capacity of the site from 80 gal/min to 200 gal/min.

Prior to treatment the water is filtered through three 50-micrometer bag filters operated at 150 pounds/square inch (lb/in^2) to remove suspended solids and preclude fouling of the tower packing or blinding of the final absorber. A 2,000-gallon polyethylene equalization tank is used for blending the groundwater prior to air stripping. This tank also serves as a holding tank to prevent the recovery wells from being pumped dry. The well pumps, if operated continuously around-the-clock, will pump the underground watertable dry. Therefore, the well pumps are operated on an intermittent basis to fill up the holding tank. Once this is accomplished, the pumps are shut down until the tank is empty and needs refilling. The tank is equipped with high- and low-level switches which activate the pumps at the recovery wells. The same type of level control system is also employed on the sump of both air strippers.

Although the plant is considered to be operating continuously, 24 hours a day, the operation is actually intermittent due to the lag time it takes for the holding tank to fill with water. As the tank is being filled, the pumps at both air strippers are emptying the sumps at each stripper. Once these sumps are emptied, they will then cut off until water is again pumped from the holding tank to the strippers and the process restarts.

The 4-foot-diameter air strippers operate in series. As the water leaves the second air stripper, it is further cleaned in a 10,000-pound, liquid-phase granular carbon absorber. The liquid-phase carbon absorber is included to remove possible nonvolatile organics from the water. It was not fully known at the time the plant was designed what type of nonvolatile organics were in the groundwater; therefore, the aqueous-phase carbon absorber was included in the design to provide additional treatment to the water as it exits the second air stripper. The water is then discharged through a 4-inch line into a nearby creek about 130 feet from the facility. Two air blowers (one/tower) are used to strip the VOCs from the water as it is pumped through the towers. Each air blower pushes about 1,000 ft^3/min through each tower. Design modeling and actual data have shown that more than 99 percent of the influent VOCs are removed by the first air stripper.

The high concentration of VOCs in the exit air stream from the first air stripper is treated by passing heated off-gas through a 10,000-pound vapor-phase carbon absorber. A 13-kilowatt (kW) heater is used to reduce humidity to less than 50 percent. Two parallel absorbers are installed to allow immediate switching to a fresh carbon bed when the online carbon is spent. Removal of the remaining VOCs by the second tower operating at a high air:water ratio will not produce significant stack emissions; therefore, no vapor-phase carbon emission system is judged necessary for this tower.

During our initial visit in November 1989, the plant was open to the environment. By the time we visited a second time in February 1990, a heated metal building had been constructed and totally enclosed the water treatment system. The building was necessary to provide freeze protection to the pumps, tanks, and associated piping and valves during the cold winter months.

During each visit to the plant, we talked to the operator from Carbon Air Services, Incorporated (CASI). CASI is the contractor responsible for the construction of the treatment facility. The operator is also responsible for collecting the day-to-day readings and ensuring that everything runs smoothly. At the conclusion of the contract operations, all the treatment equipment will be purchased by the Army and LEAD would then assume operation of the system; it was anticipated that it would take about six months for CASI to train the LEAD operators and turn the operation and maintenance over to LEAD.

4.3 SHAD

SHAD is located in Lathrop, California. It provided maintenance services for vehicles, aircraft, and industrial and medical equipment from 1941 to 1975. Organic solvents were used in these operations for degreasing, paint stripping, and paint spraying. Spent solvents and sludge from these operations were land applied. A 1981 environmental survey of SHAD determined that the contamination levels in groundwater exiting the depot exceeded acceptable criteria. Sampling studies at this time verified that the volatile organic contamination originated in the South Balloon area at the southernmost portion of the depot. Additionally, contamination in an area known as the North Balloon area has also been found at the northernmost portion of the depot. Both the South Balloon and North Balloon areas were targets for air-stripping towers to be built for use in decontaminating the groundwater.

An analysis of the groundwater at SHAD shows that it was contaminated with the following three major contaminants:

Influent	Concentration, µg/L
cis-1,2-dichloroethylene	20
Chloroform	3
Trichloroethylene	190

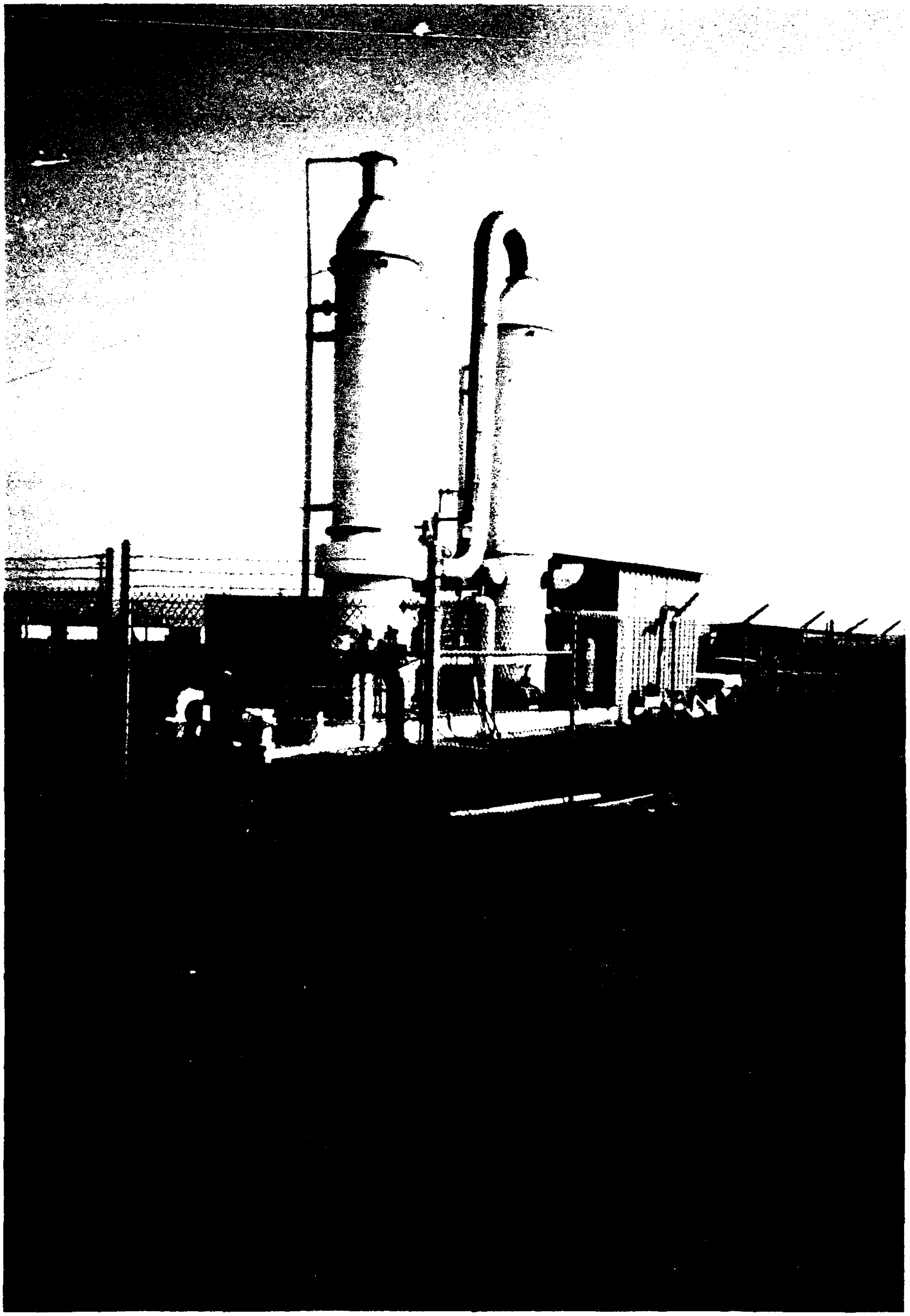
A packed-column air-stripping water treatment plant was constructed at SHAD to remediate the VOCs from the underground water aquifers.

As mentioned, there are two treatment sites operating at SHAD. One treatment site, the South Balloon area, was built in 1986 and visited in January 1990 as part of this study. The other treatment site, at the North Balloon area, was under construction in January 1991, but has since been completed and is now in operation. The process treatment plant for both sites is similar. The main difference being that the two towers at the South Balloon area are 4 feet in diameter and process 200 gal/min of water. At the North Balloon area, the two towers are 5 feet in diameter and process 300 gal/min of water. Figure 4.3-1 is a photograph of the South Balloon treatment plant. Figure 4.3-2 is a flowsheet of the process used to treat the groundwater at SHAD; the dimensions are based on the North Balloon site.

The North Balloon site at SHAD consists of two towers in series, operating continuously around the clock to process approximately 300 gal/min of water. Because of the warm climate, the treatment plant does not require an enclosed building. The control room is enclosed to protect the electronic and data-gathering equipment from the weather. The two towers are 60 inches in diameter and are constructed of fiberglass-reinforced plastic. The packing height in each tower is 9.25 feet for a total packing volume of 360 cubic feet (ft^3). The packing used in each tower is Cascade No. 1-A plastic 1-inch mini ring. The towers are operated in series so that the water is processed through one tower and then through the second tower before being discharged through an 8-inch-diameter pipe to a storm drain.

The plant currently operates using just one blower which moves air at a rate of about 3,000 ft^3/min. The air enters below the bottom of the packing level of the first tower, passes upward through the

Figure 4.3-1
VOC Water Treatment Plant at Sharpe Army Depot



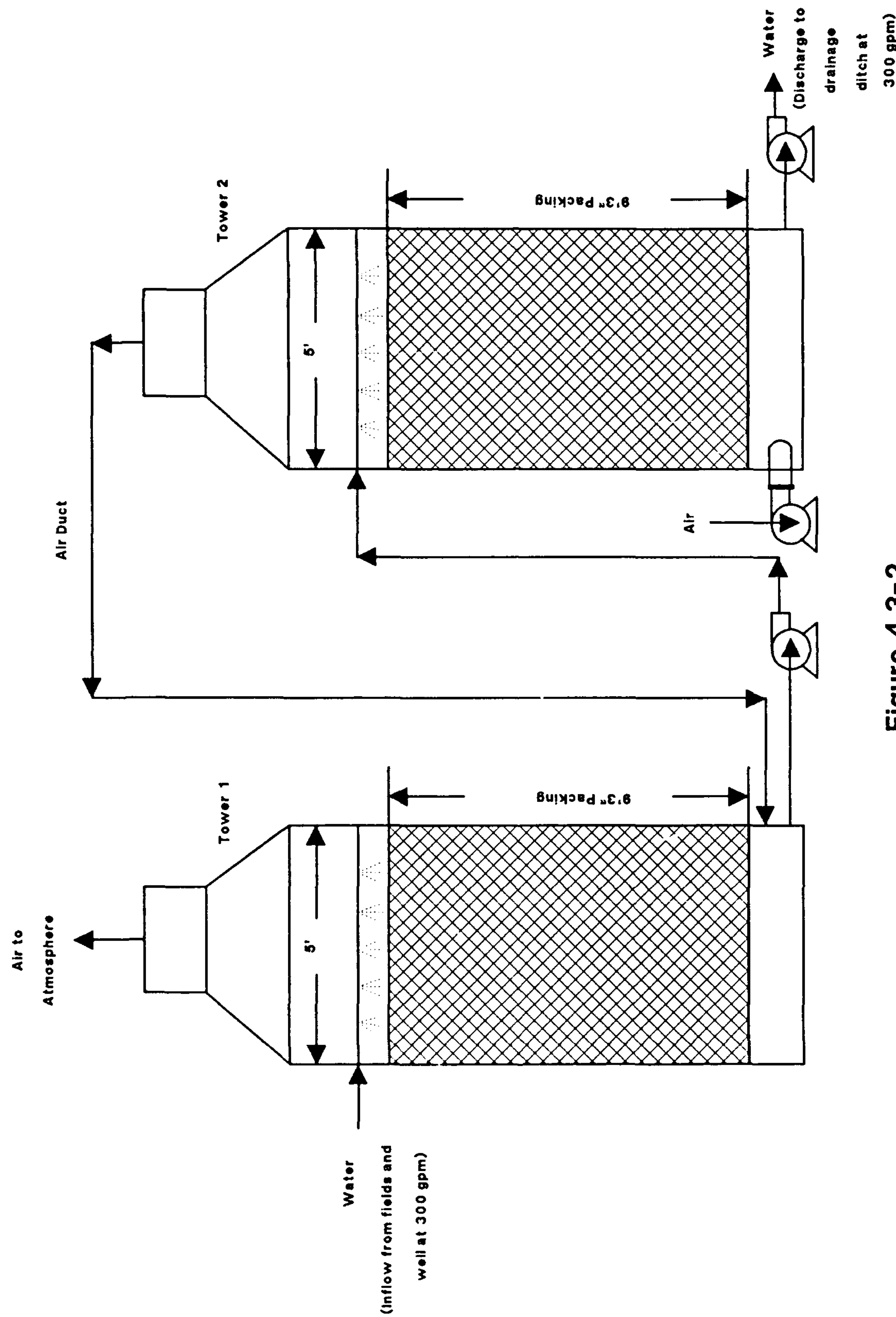


Figure 4.3-2
Flowsheet of Water Treatment Plant at Sharpe Army Depot

tower, and exits out the top of the first tower through a duct. The duct transfers the air below the bottom of the packing level of the second tower and then out the top of the second tower into the atmosphere. The plant operates at an air:water ratio of 75:1.

The water is pumped into the water treatment site from a series of boundary wells and source control wells located around the plant area. There are currently 15 boundary wells. Each well has its own pump. All of the wells pump the water into a single eight-inch pipe system. The piping coming off the well is galvanized steel. PVC pipe is used for most of the forcemain system, especially where it is laid in underground trenches before reaching the treatment site. Most of the plant piping is also PVC, although there is some carbon steel pipe which is used for transferring the water within the plant area.

The system currently operates continuously, 24 hours a day, in an automatic-control mode requiring little or no daily manual inspection. The automatic process-control system consists of a programmable analog loop controller, a six-channel multipoint microprocessor recorder, analog indicator, a 10-alarm point annunciator, magnetic flowmeters, differential pressure transmitters, insertion turbine flowmeter, float switches, and valve actuators.

The programmable controller is a microprocessor-based controller with input/output hardware enabling it to perform functions by relays, timers, and counters. The controller provides coordinated control of the equipment in the treatment plant and well fields. It includes a central processing unit, memory, input/output modules, programming unit, program loader, and all interconnecting cables.

Each well pump is provided with controls which will permit remote start/stop of each well from the treatment plant control panel. Well pumps are protected by interlocking pump controls with well water level and well pump discharge flow. Each well pump has an automatic restart if the well water level recovers after a low water level pump shutdown. There is an influent flow-monitoring loop which maintains a constant influent of water to the treatment site.

Both air strippers have water level switches which will shut down the treatment system and sound an alarm if the water level becomes abnormally high or low in the tower sumps. During normal treatment plant startups, the transfer pump at tower 1 will be started when the water level reaches a high set point in the sump. During normal treatment plant shutdown, the transfer pump at tower 1 will be stopped when the water level reaches a low set point in the sump. The discharge effluent pump at tower 2 utilizes the same type of system. A separate loop from the programmable controller also provides for process air flow rate once the axial fan is started for operation.

There is an emergency stop push button on the programmable controller which will cause the entire treatment plant and well field to stop. Pulling the emergency stop push button out will permit restart of the plant and wells. The control station also provides two process graphics displays to show the location and status of well pumps and treatment plant equipment.

V. ECONOMIC EVALUATION

5.0 Economic Evaluation

Each of the three sites were visited to obtain the necessary capital, operating, and maintenance cost data. As required by the statement of work (SOW), this economic evaluation includes the following:

- Capital cost of each facility.
- Operating and maintenance cost of each facility.
- Total life-cycle costs for each facility expressed in dollars per 1,000 gallons of water treated.
- Significant cost drivers for each facility.

5.1 Description of Facility Costs

5.1.1 Capital Costs

The capital costs for each of the facilities, all extraction wells, and the forcemain collection systems were taken from contract documents, bid documents, construction cost reports, and other data obtained at each site and/or from USATHAMA. The costs were collected and categorized according to the listings in the following paragraphs.

The costs shown for extraction and monitoring wells include well drilling, casings, pump and piping in the well, and the well head. The forcemain system includes costs for wellhouses, excavations, piping and valves to collect the water, backfill of trenches, road crossings, and site cleanup.

The cost figures presented in this report are broken down into the following categories:

- Construction Costs - These costs represent the total expenditures for materials and equipment and installation labor required to build and place in operation the air-stripping facility, the collection wells, and the forcemain system. The forcemain system cost also includes the pump and/or wellhouse costs. In each case, this work was accomplished by various subcontractors working for a general contractor. Generally the costs are for foundations, buildings, process equipment, electrical systems and instrumentation control, piping, and for mechanical systems.

- Startup Expense - This amount covers the costs of material and labor required to get the plant and equipment operating at full design capacity. It includes costs for mobilization of equipment and onsite setup by the general contractor. Decontamination of equipment is also in this category.

- Health and Safety - These costs are for medical surveillance of workers during and after construction due to handling of contaminated materials. The general contractor also included costs for the implementation of his workers' health and safety plan.

- Overhead and Profit - These costs are for the contractor's company overhead, employee benefits, and for the profit earned for completing the work required under the contract.

- Engineering - The engineering costs associated with these construction projects include all costs for the engineering salaries, travel, per diem, office expense, etc., for design of the air-stripping facility, wells, and forcemain system. Also included in this category are the costs for reviewing bids, awarding contracts, monitoring construction, and assisting operators during the startup of the plant.

- Project Management - These costs include all charges (salaries, benefits, travel, per diem, office expenses, etc.) that are normally associated with the overall responsibility of a construction project. For these air-stripping projects, these charges cover risk assessment, monitoring and coordinating other engineering contracts, monitoring performance of work, and overseeing operations and maintenance during the startup and testing of the plant. This category also covers costs for report writing and final recordkeeping.

- Disposal of Waste - These costs are for collecting and disposing of waste materials generated during construction. This includes filters and filter media, gloves, clothing, chemicals, and other contaminated materials.

Care should be used when comparing the capital costs of one facility with another due to considerable differences in design, geographical location, capacity, and method of operation.

5.1.2 Operating and Maintenance Costs

Where possible, the maintenance costs were determined from existing maintenance contracts such as TCAAP and SHAD. At LEAD, the costs were determined based on discussion with plant operators and maintenance personnel. The facilities selected for study do not have a person(s) dedicated totally to the plant. Therefore, personnel costs for operators were sometimes estimated as explained in the discussion for each site. Utility costs are included here.

5.1.3 Total Life-Cycle Cost

The total life-cycle cost (TLCC) for each facility was calculated using the guidelines of NBS Handbook #135 published for the Department of Energy. This handbook provides procedures and formats to calculate the cost effectiveness of new system designs. All existing cost data was converted to base dollars and the life of the plant was assumed to be 30 years.

The Uniform Present Worth (UPW) and the Single Plant Worth (SPW) discount factors are taken from the tables in the NBS Handbook #135. The ten-percent discount rate is defined for Federal use to be "real" rates exclusive of general price inflation. The factors are applied as multipliers to future amounts which are stated in "constant" dollars--that is, exclusive of general price inflation.

5.1.4 Significant Cost Drivers

The significant cost drivers--individual cost items that have a major impact on capital or operating cost--were determined from the capital cost information explained above, the calculated costs of utilities, and from operations and maintenance contracts. In the discussion for each facility, the significant drivers are identified and listed in individual tables.

5.2 Twin Cities Army Ammunition Plant (TCAAP) Economic Evaluation

The total capital investment for the existing TCAAP facility as constructed is summarized in Table 5.2-1. The costs include all direct and indirect charges normally associated with a capital construction project (material, labor, startup, overheads, profit, project management, and engineering). This table shows the installed costs for the treatment plant, extraction wells, and a forcemain

Table 5.2-1

Existing Facility
AIR STRIPPING OF VOCs FROM GROUNDWATER
Twin Cities Army Ammunition Plant
New Brighton, Minnesota

Capital Costs (1990 $)

Category	Treatment Plant	Wells	Forcemain & Pumphouses	Total
Construction Cost	$ 774,757	$1,026,406	$2,386,712	$4,187,875
Startup	135,930	71,861	150,429	358,220
Health and Safety	21,150	41,748	47,227	110,125
Overhead and Profit	236,225	245,889	392,143	874,257
Engineering	449,769	546,738	579,203	1,575,710
Project Management	319,862	331,523	276,882	928,267
Total Capital Cost	$1,937,693	$2,264,165	$3,832,596	$8,034,454

collection system with necessary pumphouses (in 1990 dollars). The 2,900 gal/min treatment plant as described in the process review was built adjacent to an existing water plant and used one wall as a common wall. This groundwater remediation project was completed in phases and involved different construction companies working over a long period of time resulting in higher costs due to additional mobilization/demobilization expenses, additional health and safety plans, etc.

The cost information obtained at TCAAP indicates that a total of 81 wells were installed throughout the facility. This includes 16 extraction wells, 17 return wells, and 48 monitoring wells. These wells vary in depth, diameter, and underground water flow rate. Sixteen of the wells have pumphouses installed over them for freeze protection. A complete hydrological survey was conducted to determine necessary information for well drilling. The cost of this survey is in the engineering costs for "wells" shown in Table 5.2-1.

The cost of the forcemain system and pumphouses includes approximately 17,800 linear feet of ductile iron pipe, 16 pumphouses, 16 return well structures, and other valves and controls. The pipe is installed in trenches a minimum of 7 feet below grade and ranges in size from 6 to 16 inches in diameter. Pumphouse costs include structures, pumps, controls, all electrical and mechanical systems, and controls to tie the wells to the forcemain system.

Table 5.2-2 shows the annual operating costs for the existing TCAAP facility. The capacity of the TCAAP facility is approximately 2,900 gal/min (1.524×10^9) gallons/year) of treated water. The utility cost for the air-stripping facility is for electricity only. A monthly breakdown of electrical usage was provided upon request and was used to calculate electrical cost. Total kWh at $0.0425/kWh was 1,739,561 ($73,931.34). Total kWh at $0.0443/kWh was 1,691,087

Table 5.2-2

Existing Facility
AIR STRIPPING OF VOCs FROM GROUNDWATER
Twin Cities Army Ammunition Plant
New Brighton, Minnesota

Annual Operating Costs

Cost Item:	Annual Cost (1990 $)
• Utilities	$148,846
• Professional Services (CRA)	219,502
• Maintenance (Subcontractor to CRA)	150,054
• Lab Charges	25,175
• Other O&M Costs	39,518
Total	$583,095
• Non-Annual Recurring (Non-Fuel) Costs Every Fifth Year - Tower Packing	$ 20,865

($74,915.15). Total cost for electricity was $148,846.49. Monthly usage and cost is shown on Table 5.2-3 (Note: The utility rate increased in July 1990 from $0.0425/kWh to $0.0443/kWh).

The actual operating and maintenance costs were obtained from TCAAP (Alliant Tech Systems) for the calendar year 1990. This includes all personnel costs, overheads, materials, field purchases, and lab expenses. These expenses are summarized in Table 5.2-4. The column headed "other" includes items such as supplies, truck mileage, vehicle use, computer, Xerox charges, telephone, field expenses, printing charges, and photographs. These invoices were submitted by Conestoga-Rovers & Associates Limited (CRA), Waterloo, Ontario, Canada, the consulting engineering firm with overall design, installation, maintenance, and operation responsibility.

Table 5.2-5 shows the total life-cycle cost calculations for the TCAAP facility. The costs shown represent the TLCC and the annual operating cost expressed in 1,000 gallons of water treated. The TLCC is equal to $0.2971/1,000 gallons whereas the total cost of operation and maintenance only (i.e., TLCC - capital cost) is equal to $0.1214/1,000 gallons.

One additional cost item is the replacement of tower packing. To date, no packing has been replaced. TVA's engineering estimate indicates one third of the tower packing should be replaced every five years (1/3 x 4,500 ft^3 = 1,500 ft^3 x \$13.91/ft^3 = \$20,865). This will account for the normal wear, settling, and fouling of the packing material. The cost for tower packing was taken from the capital cost report obtained at TCAAP. The replacement of tower packing is considered a non-annual, recurring (non-fuel) operating and maintenance (O&M) cost and is shown in Table 5.2-5.

Table 5.2-3

Existing Facility
AIR STRIPPING OF VOCs FROM GROUNDWATER
Twin Cities Army Ammunition Plant
New Brighton, Minnesota

Annual Power Usage and Cost

Month	Kilowatt Hours Wells	Kilowatt Hours Treatment	Kilowatt Hours Total	Power Cost ($)	Total Electrical Cost ($)
01/90	237,348	89,040	326,388	$0.0425/kWh	$13,871.49
02/90	195,170	85,200	280,370	$0.0425/kWh	11,915.73
03/90	202,320	90,840	292,847	$0.0425/kWh	12,446.00
04/90	179,336	83,280	262,616	$0.0425/kWh	11,161.18
05/90	185,709	88,080	273,789	$0.0425/kWh	11,636.03
06/90	203,711	99,840	303,551	$0.0425/kWh	12,900.92
07/90	162,960	78,960	241,920	$0.0443/kWh	10,717.06
08/90	158,751	88,320	247,071	$0.0443/kWh	10,945.25
09/90	213,979	92,280	306,259	$0.0443/kWh	13,567.27
10/90	191,556	89,520	281,076	$0.0443/kWh	12,451.67
11/90	205,976	87,240	293,216	$0.0443/kWh	12,989.47
12/90	230,345	91,200	321,545	$0.0443/kWh	14,244.44

Table 5.2-4

Existing Facility
AIR STRIPPING OF VOCs FROM GROUNDWATER
Twin Cities Army Ammunition Plant
New Brighton, Minnesota

Operating and Maintenance Contract Costs
Calendar Year 1990

Month	Invoice Number	Total Invoice Amount	Professional Service MHrs	Man Hour Cost	Subcontractor Costs	Lab Costs	Other Costs
Jan	5655	$ 75,913.08	696.75	$ 35,248.49	$ 32,572.42	$ 6,343.41	$ 1,748.76
Feb	5869	25,567.59	346.0	16,109.85	9,155.00		302.74
	5871	10,331.58	162.0	10,203.07			128.51
Mar	6155	54,717.84	110.0	5,301.90	39,017.62	10,112.20	286.12
Apr	6347	8,045.52	160.5	7,022.82	240.00		782.69
Mar-Apr	6380	34,752.67		31,121.00	162.50	689.41	2,779.76
May	6820	2,393.06	43.0	1,804.56			588.50
Jun	6807	44,283.43	769.5	33,386.21	9,115.38	410.00	1,371.84
Jul	7259	21,650.65	403.0	18,429.73	811.75	880.20	1,528.97
	7260	1,170.37	17.5	852.34	234.20		83.83
Aug	7505	30,049.53	40.5	2,149.11	27,665.00		235.42
	7506	11,515.97		11,281.75			234.22
	7548	31,228.14	50.5	2,580.71	25,971.13		2,676.30
Sep	7690	7,054.89	63.0	2,824.41	3,214.87		1,015.61
	7691	12,564.43	255.5	11,718.97		538.20	307.26
	7750	7,235.79	51.5	2,083.58	166.00	4,927.60	58.61
Oct	8042	929.74	22.5	896.12			33.62
	8044	1,421.95	27.5	1,181.56			240.39
	8045	3,422.21	44.0	1,920.15			1,502.06
	8120	4,159.44	102.5	4,002.36			157.08
Nov	8280	1,236.33	16.0	705.82			530.51
	8340	5,947.30	129.0	5,124.12		637.00	186.18
	8343	1,928.00	45.0	1,869.72			58.28
	8355	20,643.74	45.5	1,875.12	250.00		18,518.62
Dec	8635	8,451.80	146.5	6,112.04	1,478.21	637.00	224.55
	8636	3,140.35	67.0	3,022.55			117.80
	8637	493.36	10.0	422.35			71.01
	8638	3,999.93	7.0	251.13			3,748.80
Totals		$434,248.69	3,831.75	$219,501.55	$150,054.08	$25,175.02	$39,518.04

Table 5.2-5

Existing Facility
AIR STRIPPING OF VOCs FROM GROUNDWATER
Twin Cities Army Ammunition Plant
New Brighton, Minnesota

Total Life-Cycle Cost

		Present Value
1.	Capital Cost - Total Investment	$ 8,034,454
2.	Annual Energy Cost ($148,846.49 x 9.58) 9.58 = UPW Discount Factor	1,425,949
3.	Annual (Non-Fuel) O&M Cost ($434,249 x 9.43) 9.43 = UPW Discount Factor	4,094,968
4.	Non-Annual Recurring (Non-Fuel) O&M Cost	31,089

Year	Amount	SPW Factor	Cost
5th	$20,865	.62	$12,936
10th	20,865	.39	8,137
15th	20,865	.24	5,008
20th	20,865	.15	3,130
25th	20,865	.09	1,878
			$31,089

Total Life-Cycle Cost $13,586,460

Capital Cost/1,000 gal = .1757
(TLCC - opn costs)

Opn/1,000 gal = .1214
(TLCC - capitalcost)
TLCC/1,000 gal = $.2971

Table 5.2-6 shows significant cost drivers for the existing TCAAP facility. These costs shown are direct construction costs only and do not include engineering and project management costs.

5.3 Letterkenny Army Depot (LEAD) Economic Evaluation

The total capital investment for the existing LEAD facility as constructed, is summarized in Table 5.3-1. The costs include all direct and indirect charges as described in Section 5.1 of this report. The cost data received from LEAD was the March 1989 contract pricing proposal from Hunter/ESE, the primary contractor for design and construction of the facility. The design included an insulated metal building with a complete heating system to prevent freezing in the winter. Although this facility was designed to treat approximately 200 gal/min, the cost information contained in this report is for three extraction wells that only produce 80 gal/min. Four monitoring wells were also installed in the original design. Seven additional extraction wells have since been installed but the cost information has not been made available for inclusion in this writing. Based on the costs for the three extraction wells initially installed, the total costs for seven more would be approximately $513,100 or an estimated value of $73,300 each. This additional capital cost will bring the estimated value of the installed system to $2,054,145.

At LEAD's facility, the small costs for the forcemain collection system are included with the cost of the treatment plant. This system consists of approximately 400 feet of one-inch CPVC piping buried a minimum of 48 inches below grade. No pumphouses or wellhouses were necessary for freeze protection due to pumps and piping underground. Because of the closeness of the three wells to the treatment facilities, the piping costs of the forcemain collection system are not significant to this project. The costs for the hydrological survey are included in the engineering costs for the wells.

Table 5.2-6

Existing Facility
AIR STRIPPING OF VOCs FROM GROUNDWATER
Twin Cities Army Ammunition Plant
New Brighton, Minnesota

Significant Cost Drivers

Capital Costs:	(1990 $)
• Process Equipment	
- Stripping Towers	$296,821
- Transfer Pumps	47,880
• Wet Wells	142,740
• Enclosure	64,855
• Extraction Monitor and Return Wells (81)	
- Well Drilling (Approximately 16,750')	399,633
- Well Casings	241,095
• Pump Houses	775,964
- 6 @ $48,134	
- 10 @ $48,716	

Annual Operating Costs:	
• Utilities	$148,846
• Professional Services (CRA)	219,502
• Subcontracted Maintenance Repairs	150,054

Table 5.3-1

Existing Facility
AIR STRIPPING OF VOCs FROM GROUNDWATER
Letterkenny Army Depot
Chambersburg, Pennsylvania

Capital Costs (1990 $)

Category	Plant	Wells[4]	Forcemain[2]	Total
Construction Cost	$ 248,735[1]	$ 209,738		$ 458,473
Startup	344,775[5]			344,775
Health and Safety[3]				
Overhead and Profit	73,322	28,628		101,950
Engineering	326,141	220,530		546,671
Project Management	57,965	31,211		89,176
Total Capital Investment	$1,050,938	$ 490,107		$1,541,045
Total Estimated Value of Seven Additional Wells		513,100		513,100
Estimated Capital Investment	$1,050,938	$1,003,207		$2,054,145

[1] Includes mobile Aquifier Test Treatment Unit ($61,100).
[2] Included with plant cost.
[3] Not listed as a separate cost.
[4] Costs for three initial extraction wells. Seven added later, cost not available.
[5] Includes operating costs (six months) for startup ($247,000).

The annual operating costs are shown in Table 5.3-2 and include the electrical costs, operators, maintenance costs, and replacement of carbon for the absorbers. The electrical usage is metered at the treatment site. Since the plant has not been in operation for a year, the total annual consumption was estimated based on the latest information obtained from LEAD through December 1990. The electrical costs include ten well pumps operating as explained earlier. The charges for electricity at the present rate of $0.0350 per kilowatt-hour is $2.72 per hour. This calculates to be $23,827 on an annual basis. This information was received by telephone in January 1991 from personnel at LEAD. At the time of the site visits by TVA personnel, the contractor had personnel in place to complete the installation, fine tune the system, and train LEAD personnel for operations and maintenance.

According to Peters and Timmerhaus, Plant Design and Economics for Chemical Engineers, Third Edition, maintenance contracts for this type of operation generally run about two to six percent of the total capital investment. Without a maintenance contract in place, the maintenance costs have been estimated to be $58,230 per year. This amount has been used in Table 5.3-2 to represent a realistic maintenance cost of approximately 2.8 percent of the total capital investment.

The carbon used in the carbon absorber has to be replaced every 90 days in the gas phase. This amounts to 10,000 pounds of carbon being replaced. Two 10,000-pound containers are installed in parallel to allow removal of either and keeping one online during change out. The cost of the carbon is $2.36 per pound for gas-phase carbon and an additional $0.90 per pound for reactivation after use in the gas phase. A total of 40,000 pounds will be used each year.

One operator is required one hour each day to record meter readings, take samples, and make adjustments as necessary for day-to-day operations. With all overheads and benefits, this cost will be

Table 5.3-2

Existing Facility
AIR STRIPPING OF VOCs FROM GROUNDWATER
Letterkenny Army Depot
Chambersburg, Pennsylvania

Annual Operating Costs

Cost Item:	Annual Cost (1990 $)
• Operating Personnel	$ 7,621
• Utilities	23,827
• Maintenance	58,230
• Carbon	132,400
• Non-Annual Recurring (Non-Fuel) Cost Every Fifth Year	$ 2,968

approximately $7,621 per year. This is an estimated cost based on discussions with operators at the treatment plant during one visit.

An additional cost item to be included in the total operating and maintenance costs is the replacement of tower packing every five years. One third of the total volume will be required to be replaced at a cost of $2,968 (1/3 x 503 ft^3 = 168 ft^3 x $17.70/$ft^3$ = $2,968). This replacement is indicated in Table 5.3-2 and Table 5.3-3 which shows the total life-cycle cost calculations for the LEAD facility. The costs are representative of the TLCC and the annual operating cost is expressed in 1,000 gallons of water treated. The TLCC is equal to $1.3185/1,000 gallons with the carbon absorbtion units and $0.8814/1,000 gallons without the carbon units. The operating costs calculate to be $0.6671/1,000 gallons with the carbon units and only $0.2712/1,000 gallons without the carbon units.

Table 5.3-4 shows the significant cost drivers for the existing facility. These costs are construction costs only and do not include engineering, project management, or other indirect costs. The installation at LEAD is more complex in that the Pennsylvania Department of Environmental Resources (PADER) requires that a carbon absorption system be installed in addition to the air stripping towers. The capital costs shown in Table 5.3-1 includes both gas and liquid carbon absorption units.

5.4 Sharpe Army Depot (SHAD) Economic Evaluation

The total capital investment for the existing SHAD facility as constructed in the North Balloon Area is summarized in Table 5.4-1. These costs include all direct and indirect charges as explained in previous sections of this report. The North Balloon Area treatment facility at SHAD will process 300 gal/min and uses a storm drain to dispose of the treated water. The treatment facility does not have

Table 5.3-3

Existing Facility
AIR STRIPPING OF VOCs FROM GROUNDWATER
Letterkenny Army Depot
Chambersburg, Pennsylvania

Total Life-Cycle Cost

		Present Value
1.	Capital Cost - Total Investment (with carbon absorbers)	$ 2,054,145
2.	Annual Energy Cost ($23,827 x 9.65) 9.65 = UPW Discount Factor	229,931
3.	Annual Recurring (Non-Fuel) O&M Cost ($198,251 x 9.43) 9.43 = UPW Discount Factor	1,869,507
4.	Non-Annual Recurring (Non-Fuel) O&M Cost	4,422

Year	Amount	SPW Factor	Cost
5th	$ 2,968	.62	$ 1,840
10th	2,968	.39	1,158
15th	2,968	.24	712
20th	2,968	.15	445
25th	2,968	.09	267
			$ 4,422

Total Life-Cycle Cost $ 4,158,005

	With Carbon Absorbers	Without Absorbers
Capital Cost/1,000 gal (TLCC - opn costs)	$ .6514	$ .6102
Opn/1,000 gal (TLCC - capital costs)	$ .6671	$ .2712
TLCC/1,000 gal	$1.3185	$ .8814

Table 5.3-4

Existing Facility
AIR STRIPPING OF VOCs FROM GROUNDWATER
Letterkenny Army Depot
Chambersburg, Pennsylvania

Significant Cost Drivers

Capital Costs:	(1990 $)
• Process Equipment	
- Stripping Towers	$ 34,712
- Carbon Absorbers	84,310
• Metal Building	27,100
• Extraction and Monitoring Wells (7)	209,738
• Seven Additional Extraction Wells	232,700

Annual Operating Costs:	
• Carbon Replacement	$132,400
• Maintenance	58,230

Table 5.4-1

Existing Facility
AIR STRIPPING OF VOCs FROM GROUNDWATER
Sharpe Army Depot - North Balloon Area
Lathrop, California

Capital Costs (1990 $)

Category	Plant	Wells	Forcemain	Total
Construction Cost	$ 236,223	$ 353,588	$ 129,789	$ 719,600
Startup	16,132	21,562	8,881	46,575
Health and Safety	52,480	68,382	28,834	149,696
Overhead and Profit	59,056	96,824	32,447	188,327
Engineering	62,556	95,800	28,947	187,303
Project Management	30,224	39,382	16,606	86,212
Disposal of Waste	2,200	3,250		5,450
Total Capital Cost	$ 458,871	$ 678,788	245,504	$1,383,163

nor does it need any freeze protection as does the plants at TCAAP and LEAD. The cost information in Table 5.4-1 is for the treatment plant, the extraction wells, and the forcemain collection system and represents a one-time expenditure for design and construction.

The capital cost information obtained from SHAD indicates that 14 extraction wells were drilled and cased in the original North Balloon Area facility. In 1990, one additional well was drilled and connected to the North Balloon treatment facility. The costs shown in Table 5.4-1 reflect this addition and were included with the original construction cost. Due to the mild climate in California, none of the well sites required a pumphouse to be constructed to protect them. Each wellhead was protected by steel posts set in concrete that serve as a traffic barrier.

The forcemain collection system consists of approximately 3,880 feet of underground PVC pipe ranging in size from one inch in diameter to six inches in diameter and is buried a minimum of three feet below the surface.

The actual operating and maintenance costs were taken from a firm, fixed-price maintenance contract between SHAD and Calcon Systems, Inc., San Ramon, California. The cost breakdown for this contract is shown in Table 5.4-2 and is for preventative maintenance, calibration, service, and repairs. This fixed-price contract was for the VOC air-stripping facility at Sharpe Army Depot that is in operation now (South Balloon area). This plant is designed and operated nearly identical to the facility constructed in the North Balloon Area. For this report, the operating and maintenance costs for the South Balloon plant have been used to project the expected costs for the North Balloon plant.

Table 5.4-2

Existing Facility
AIR STRIPPING OF VOCs FROM GROUNDWATER
Sharpe Army Depot - North Balloon Area
Lathrop, California

Annual Maintenance Costs (Contract)
Calendar Year 1990

Supplies/Services	Quanitity	Amount
Weekly Services (Inspection Reports)	52	$21,840
Monthly Service	12	5,040
Labor (Scheduled)	500 MH	21,000
Labor (Emergency)	56	2,352
Parts, Material, and Equipment Rental		15,000
		$65,232

Contract is with Calcon System, Inc., San Ramon, California.

The utility costs for the North Balloon plant was also determined from the air-stripping unit for the South Balloon Area. The utility records show 250,308 kWh of electricity was used at this plant site. The current rate for electricity for the Lathrop, California region is $0.0387 per kilowatt hour. This cost calculates to be $9,687 per year. Electricity is the only utility cost included in the operation of the plant. The annual operating costs are summarized in Table 5.4-3.

An additional cost item to be included in the total operating and maintenance costs is the replacement of tower packing every five years. Approximately one third of the total volume of tower packing will be required to be replaced every 5 years at a cost of $2,096. This is equivalent to 121 cubic feet of packing ($1/3 \times 363\ ft^3 = 121\ ft^3 \times \$17.32/ft^3 = \$2{,}096$). This replacement is shown in Table 5.4-4 showing the total life-cycle cost for the facility. The costs shown in this table are representative of the TLCC and the annual operating costs expressed in 1,000 gallons of water treated. The TLCC is equal to $0.4442/1,000 gallons and the annual operating cost is equal to $0.1518/1,000 gallons of treated water.

Table 5.4-5 shows the significant cost drivers for the North Balloon Area treatment facility. The costs shown are construction costs only and do not reflect costs for engineering or project management.

Table 5.4-3

Existing Facility

AIR STRIPPING OF VOCs FROM GROUNDWATER

Sharpe Army Depot - North Balloon Area

Lathrop, California

Annual Operating Costs

Cost Item	Annual Cost
• Utilities	$ 9,687
• Maintenance Labor[1]	23,352
• Inspection Services[1]	26,880
• Parts, Material, and Equipment Rental[1]	15,000
	$74,919

[1] Items listed on maintenance contract with Calgon Systems, Inc.

Table 5.4-4

Existing Facility
AIR STRIPPING OF VOCs FROM GROUNDWATER
Sharpe Army Depot - North Balloon Area
Lathrop, California

Total Life-Cycle Cost

		Present Value
1.	Capital Cost - Total Investment	$ 1,383,163
2.	Annual Energy Cost ($9,687 x 10.31) 10.31 = UPW Discount Factor	99,873
3.	Annual O&M Cost ($65,232 x 9.43) 9.43 = UPW Discount Factor	615,138
4.	Non-Annual Recurring (Non-Fuel) O&M Cost (Replacement of packing)	3,123

Year	Amount	SPW Factor	Cost
5th	$ 2,096	.62	$1,300
10th	2,096	.39	817
15th	2,096	.24	503
20th	2,096	.15	314
25th	2,096	.09	189
			$3,123

Total Life-Cycle Cost $ 2,101,297

Capital Cost/1,000 gal (TLCC - opn cost)	= $ .2924
Opn Cost/1,000 gal (TLCC - capital cost)	= $ .1518
TLCC/1,000 gal	= $ .4442

Table 5.4-5

Existing Facility
AIR STRIPPING OF VOCs FROM GROUNDWATER
Sharpe Army Depot - North Balloon Area
Lathrop, California

Significant Cost Drivers

Capital Costs	(1990 $)
• Process Equipment	
- Stripping Towers	$ 64,588
• Extraction and Monitoring Wells	
- Well Pumps	29,925
- Pump Control Panels	56,430
- Well Drilling and Casing	95,162
• Forcemain Collection System	
- Railroad Track Crossing (Borings)	54,577
Annual Operating Costs	
• Labor (Maintenance)[1]	23,352
• Weekly Inspections and Reports[1]	21,840

[1] Item listed on maintenance contract with Calgon Systems, Inc.

VI. CONCLUSIONS AND RECOMMENDATIONS

Based on the published technical literature surveyed and the actual data collected at the three operating sites, the following conclusions and recommendations can be made.

- Treatment of VOC-contaminated groundwater by stripping with air in a packed tower is usually the least expensive and most direct route to take for removing contaminants from water.

- Several variables will affect tower design for an air stripping unit. These include the liquid flow rate through the tower, water temperature, contaminant concentration in the influent water supply, desired effluent contaminant concentration, air:water mass ratio, characteristics of tower packing, and the height of the packing/tower.

- Because of the concentration levels of the contaminants in the water at LEAD and due to existing environmental regulations on emissions, carbon adsorption is required on the effluent water and the exit air from the first tower operating series.

- Because of the vast differences in design parameters and methods of operation, the plants should not be directly compared with each other based on costs alone.

- An independent organization should review site assessments, design layouts, and bid proposals before contracts are awarded for new facilities. Also, construction, startup, and operation should be better monitored to provide USATHAMA with more complete and timely operating and cost information for each site.

- There is economy of scale in that the capital and operating costs per 1,000 gallons of treated water declines as the flow rate increases.

- A consistent format should be used to record and report costs and operating data.

- Except for the costs of LEAD, the reported TLCC and operating costs are within the ranges published in Environmental Science Technology, Vol. 22, No. 10, 1988.